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"Pioneers In Compact Power"

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Research & Development Study
of the Silver-Cadmium Couple
for Space Application

Final Report

Contract No. NAS 5-3452
Final Progress Report
1 July 1964 to 30 September 1964
National Aeronautics and Space Administration
Goddard Space Flight Center
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ABSTRACT

23275
The goal of this contract was to provide an insight into basic problems associated with the sealed silver oxide-cadmium system, under satellite operating conditions. Specifically, the orbital regimes which were used in cell evaluation were the 100 minute (35% depth of discharge) and 24 hour (70% depth of discharge) regimes.

Although still in relatively early stages of development, cell improvements such as, (1) wet-proofed cadmium electrodes to increase gas recombination, (2) low density positive electrodes with improved efficiencies on cycling, (3) cells which do not show evidence of hydrogen evolution on overcharge because of lower extent of negative charge, and (4) a new separator wrap which gives 90% greater cycle life to silver shorting are felt to be advances in the "state of the art". Successful operation of cells on the Ag_2O level at better than 60% of theoretical Ag_2O capacity has also been shown to be feasible, but only in combination with low recharge rates.

The finding that the mechanism of gas recombination on cadmium is kinetically limited, and the acceleration of oxygen recombination by catalytic metals such as nickel and silver, and increased reaction rates at lower KOH concentrations are of particular interest in the problem areas of sealed cell operation.

The decrease of the negative plate efficiency through the formation of carbonates and inactive metal by reaction products from the separators during cycling, and the effect of separator debris on oxygen recombination are also noteworthy. The results of this last quarter of the investigation are briefly summarized below.

Two groups of cells operating on the short and long orbit regimes have completed 1400 and 160 cycles respectively. Reference electrode readings during a recent deep cycle indicated that most short orbit cells were positive limited on charge and negative limited on discharge, while most long orbit cells were negative limited both on charge and discharge. Four of the long orbit cells failed to come up to voltage (1.6) on the first charge following the deep discharge; evidently, this was due to silver shorting.

Four short orbit cells selected at random were dissected after 1200 cycles to determine individual Cd electrode capacities and to study the plate structures by metallographic microscope.

Several cells designed to show the effects of high temperature rapidly and which feature a combination of single layers of C19 and PVA with a separator inert to oxidation by silver completed 76 high rate deep cycles at 50°C before shorting; the controls shorted at cycle 37.

A 50°C stand-cycle test to determine the effect of S-1-51-1 treated separators on cell performance has been in progress for 50 days. During this time, the cell fabricated with S-1-51-1 Visking lost the least amount of capacity.

The performance of cells fabricated with partially wet-proofed cadmium negatives is still satisfactory after 1200 shallow cycles. Although the oxygen recombination rate has decreased by over 50%, it is still larger than the controls.

Cells charged to different extents of negative capacity have completed 335 short orbit shallow cycles. Gas analyses show no hydrogen in cells in which the cadmium is initially charged to below 60% of theoretical.

Three groups of 7-cells which incorporate various design improvements are being built for delivery to NASA.

Cells containing various metallic additives have completed 94 cycles, maintaining about 49% of theoretical argentous capacity on the long orbit.

BODY OF THE REPORT

1. Phase 1

1.1 Cell Tests

Twenty-four cells, which include variations in electrode density, separator system, and electrolyte concentration are presently being evaluated on the 100 minute and 24 hour orbital cycling regimes. They have completed 1400 and 160 cycles respectively for the two regimes.

Four of the short orbit cells were selected at random and dissected in the charged condition after 1201 cycles, to determine the effect of prolonged cycling on the negative electrodes. One negative plate from each cell was chemically analyzed to determine the percentages of Cd, Cd(OH)₂, and CdCO₃.

Complete results of the analyses are shown in Table I. At the same time, two electrodes, from each of the four cells, were fabricated into dummy cells containing one negative and two positive electrodes and were cycled as follows; in order to determine material efficiency following both high and low rate charging.

One set of cells were given three cycles at 100 ma/in² discharge and 65 ma/in² charge. The second set was discharged at the same rate, however, the charge rate was reduced to 19 ma/in². Following these cycles the negatives were removed from the dummy cells and analyzed, as above, for Cd and its compounds. Those results are also included in Table I.

The cycle results for all of the above dummy cells containing similar anodes were the same. The capacity data for one sponge cadmium electrode (cell #6) and one impregnated cadmium electrode (cell #30) are shown in Figures 1-4, as representative of the groups. The data show that for the sponge electrodes from cell #6, the increase in capacity during the dummy cycles, corresponds fairly closely to the increases in the Cd metal content and a decrease in amount of CdCO₃. The mechanism for the capacity improvement is, therefore, the increase in CdCO₃ charge acceptance at the lower current density. The change in Cd metal content of the sintered Ni plaque was insufficient to be observed as a capacity increase. The actual working weight of cadmium increased from 43% to 52% during the low rate charge cycles. Earlier work (see Fourth Quarterly Report, this program) showed that after 600 cycles the working weight of cadmium was increased to 65% by the same low rate procedure. The inability of the anode to discharge completely (i.e. approximately 52%) is probably due to a densification of the cadmium metal during the 1200 cycles.

When negatives from cell #70, containing a PVA separator were tested in a similar manner, little difference in capacity was obtained. The data in Table I shows that after the low rate charges, the concentration of CdCO_3 in these electrodes was not decreased. The inability of low rate charging to activate the CdCO_3 in cell #70 is probably due to the fact that the cadmium salt formed in the presence of PVA solubles is not CdCO_3 , but rather some electrochemically irreversible organic salt.

In order to determine the effect of cycling on the nature of the cadmium metal crystal, specimens of three different sponge cadmium electrodes were prepared for microscopic analysis by impregnating the electrodes, under vacuum, with a methacrylate resin. They were then cut, polished, and mounted. Photomicrographs were taken at 100, 200, and 400 diameters. The photographs are shown in Figs. 5-8.

Inspection of the uncycled control plates (Fig. 5) shows the structure to consist of fairly densely packed cadmium, with fibrous tangled structures at the surface. An examination of the cycled electrode from cell #6 (Fig. 6) shows that cycling results in the fibrous structure extending further into the body of the electrode. Furthermore, the pores are more numerous and larger than in the control. At 400 x magnification the fibrous structure becomes more apparent.

The structure of the negative electrode from cell #70, constructed with PVA separator (Fig. 2) is completely different from either the control or the negative from cell 6, containing a C-19 separator. The photographs show that this plate has very little porosity and that the structure is non-uniform with large, bright, smooth crystals protruding from the plate. It is apparent that the solubles in the PVA separator effect the crystal habit of cadmium metal.

As one of the construction parameters being studied, cells were built using variations in negative electrode density. Each pair (15&16, 17&18, 5&6) contained negative plates pressed to one of the three densities, 2.3, 2.8, and 3.3 g Cd/cc. The positives were HC silver pressed to 4.8 g Ag/cc. The separator system was (+)2NY/6C-19(-) and all cells were filled with 42% KOH. The even numbered cells are being cycled on the 100 minute regime and the odd numbered cells on the 24 hour regime.

The cells were initially given several deep cycles at room temperature, -15°C and $+50^\circ\text{C}$. During these initial cycles the capacities of the cells containing the densest negatives were slightly superior. The cells were then subjected to shallow cycling on both the long and short orbit regimes. Deep discharge cycles on these cells after 750 and 1200 cycles on the short orbit, and 70 and 160 cycles on the long orbit showed that the cells fabricated with the densest negatives were delivering from 17-22% better capacity than cells made with either of the two lower density negatives, (Figures 9 and 10).

Deep discharge results on the cells not removed for dissection after 1200 and 160 cycles on the short and long orbit regimes respectively are shown in Tables II and III. As can be seen, the cells on short orbit regime show better capacity maintenance than those on the long orbit.

The cause for the poorer performance on the long orbit is the attack of the separator by silver during the extended charge time. This results in the formation of carbonate or other acidic organic anions. These latter ions react with the electrolyte which result in a reduction in hydroxyl ion concentration. This decrease in hydroxyl ion concentration is shown in Table IV.

The data also show that cells 69-73, which were built with PVA separators, contain the highest concentration of K_2CO_3 , and lowest concentration of free hydroxyl.

Data from Table II and III, for cells with a Cd plate density of 2.8 g/cc, show that on the short orbit the capacities of cells containing C-19 separator was 2.72 AH; for cells containing a PVA separator system the capacity was 2.45 AH. On the long orbit the capacities were 2.46 and 2.24 AH respectively. However, when the negatives were removed from the cells and cycled in fresh electrolyte all electrodes of the same type behave similarly. At this time, it must therefore be concluded that the only observed property of PVA separator that effects cell performance is the change in electrolyte concentration. Further studies on the effects of separators on electrode performance is indicated.

1.2 Changes in Properties of Separator Materials

Six cells have been built with various separator systems, both cellulosic and non-cellulosic in order to study the effect of these materials on performance characteristics on the 100 minute orbit regime. This regime was used to accelerate the evaluation. They vary in type of separator system used as follows:

Cell #	Separator System
150	(+)1NY/2Visking(fibrous)/(-)/1 Viskon R-75D
151	(+)1NY/6 PUD-O-300/(-)/1 Viskon R-75D
152	" " " " " " " " / 1 Pellon - 10 mil
153	(+)1M1406/3 Visking/(-)
154	(+)1M1401/1 Polypor-WA/1 Visking fibrous/(-)/1 Pellon 10 mil
155	(+)1EM1470/2 XPE140/50/4 Permion 600/(-)/1M1410

After a series of evaluation deep cycles at RT, -15°C and $+50^{\circ}\text{C}$ which were presented in the results of report #4, the cells were placed on the short orbit life-cycle regime. At cycle 500, the cells were deep-discharged to determine their capacities; the results are shown in the table below.

Cell #	AHO	AHI	Limiting Electrode		g Ag/AH
			Discharge	Charge	
150	3.05	3.15	negative	positive	3.63
151	2.86	2.95	neg. & pos.	"	3.86
152	2.75	2.50	negative	"	4.05
153	3.40	3.50	positive	"	3.26
154	cell blew up		-	-	-
155	1.70	1.65	negative	negative	6.55

The data show that performance with Visking casing cells is excellent. The capacity of cell 155 is quite poor which is undoubtedly due to the highly resistant XPE 40/50 separators.

In another separator test, cells were constructed with S-1-51-1 treated Visking and Cl9 separators. Early results with treated Cl9 had shown that these materials were quite resistant to oxidative attack by silver. It can be seen from Figure 11 that the rate of increase of K_2CO_3 (which is a measure of extent of silver attack) was somewhat lower for treated separator than for the control cells during the charged stand period. However, after 155 cycles on 100 minute orbit at 50°C , the concentration of K_2CO_3 rose to about the same value for both systems. Table V shows the capacity data for the cells fabricated with treated and untreated Cl9 as well as Visking. It can be seen that the cells with Visking exhibit about 15% better capacity; also, the treated materials appear slightly better than the untreated separators.

In another separator test, cells were constructed using a special wrap with one RAI-XPE 40/50 positioned between turns of the main separator which was either Cl9 or PVA. The objective here was to use the inert film to interrupt the continuous silver trails which normally form through these separators, and thus to extend cell life. These cells were constructed with only 3 layers of separator, since the cells were designed to fail quickly at high temperatures.

The cells have been deep cycled at rates equivalent to the short orbit regime, and are left standing charged at frequent intervals to observe whether shorting has occurred. The data in Figure 12 show that the two cells with XPE delivered good capacity until cycle 70 before shorting, while the controls shorted after 37 cycles.

Irradiation grafted polyethylene is frequently non-uniform. This results in areas of the membrane that cannot be easily wetted, thus increasing the internal resistance of the cell. It would therefore be desirable to study other inert materials, such as polypropylene, asbestos, Acropor, and Polypor WA on a similar regime. The performance of inert materials at room temperature and -15°C should also be studied because at these temperatures resistance of the films become a limiting factor in the cell capacity.

1.3 Review of Studies in Phase I

This phase which comprised items #1, 4, 5, and 7 in the NASA statement of work, dealt with an investigation of the reactions occurring at the positive and negative electrode during cycling, and the characteristics of silver and cadmium plates of various construction.

Data from limited cycling tests clearly indicate two distinct reactions occurring at the negative electrode which decrease the electrochemical efficiency of cadmium.

The reaction of separator debris with uncharged negative material ($\text{Cd}(\text{OH})_2$) lowers the efficiency of the plates through formation of CdCO_3 and other organic salts. Experiments run on single electrodes show that a large percentage of the " CdCO_3 " can be activated by a low rate charging procedure. Photomicrographs of cycled negative electrodes indicate that the second passivating mechanism involves a recrystallization of the cadmium. This mechanism appears to be much less reversible, at low rates of charge, than does the carbonation of the $\text{Cd}(\text{OH})_2$. The decrease in utilization of the Cd may be directly related to a decrease in the real surface area of the plates. Also, the separator reaction products from PVA appear to be accelerating the recrystallization process. Electrical and chemical data show that about 60% of the available cadmium metal is "working" after prolonged cycling. It has also been observed that the negative on the first charge accepts 85 to 95% of theoretical capacity, depending on the current density before gassing, but only 60% of the input is delivered on the subsequent discharge. This may be due in part to poor conductivity between the grid and active material. However, it is more likely that the utilization is affected by the initial particle size (surface area) of the active material.

Results on one cell with supported cadmium electrodes (in a nickel matrix) show that they retain their activity longer than do sponge electrodes. It has been found that the impregnated electrodes after 1200 shallow cycles on the short orbit regime show 60% of their initial capacity, while the pressed electrode capacity had decayed to about 40%. However, the utilization based on total plate weight was better for the pressed than for the impregnated electrode.

Improvements in the utilization of the silver electrode (at high rates) have been achieved by decreasing the density of the active material from 4.8 g/cc to 4.0 g/cc. The capacity was 20% better on a weight basis, after 750 cycles on the 100 minute orbit.

An investigation of separators has led to the use of a new type of wrap, for delaying penetration by silver. This wrap consists of an irradiated grafted polyethylene membrane placed between the main separators (e.g. PVA or C-19). This wrap has resulted in a 90% increase in cycle life, where the failure mode is silver shorting.

Cycle data from cells fabricated with Visking sausage casing has indicated that this separator material is very promising for use over the temperature range -15 to +50°C.

2. Phase 2

2.1 Gas Recombination in Cells

The effectiveness of wet-proofed cadmium negatives for gas recombination has been investigated. A series of experiments with individual plates initially showed about 100% more rapid oxygen recombination than standard pressed CdO plates. In order to evaluate this property in cells, four cells were built with treated cadmium negatives. Two of these had Pellon interseparator systems with two different quantities of electrolyte. The third and fourth were built with nylon and Cl9, and contained a "normal" amount of electrolyte.

Following evaluation cycles, and oxygen recombination experiments (which were presented in report #4), the cells were placed on the 100-minute cycling regime. After 1200 shallow cycles the recombination rates and the capacities were checked for each cell. The results are given in Table VI. It is evident from the data that the recombination rate had decreased sharply with cycling. There are several possible explanations for the decrease in recombination of oxygen with the negative electrode.

One possibility is that the negative electrode, upon recrystallization, has lost the structure required for the heterogeneous reaction. A second possibility is that the soluble reaction products of the separator have coated the electrode surface, thus preventing diffusion of the gas to the active surface. A third possibility is a change in the polarization of the cadmium electrode to a point where the overpotential of O_2 is not exceeded. The actual mechanism must await further studies.

The results of cycling tests on the wet proofed electrodes are also important from a capacity standpoint. They show that the performance of electrodes with the wet proofing additives is quite satisfactory after prolonged cycling.

2.2 Effect of Extent of Negative Formation on Gas Evolution

Results presented in the last quarterly report established the optimum state of charge for the cadmium electrode to be between 60-80%, when a Cd:Ag ratio of 1.5:1 is used. However, it was thought that for prolonged shallow cycling it would be advantageous to charge only to about 60% of the Cd on the first cycle. The surplus of $\text{Cd}(\text{OH})_2$ would then preclude hydrogen evolution during subsequent charging. To determine the long term effect of the state of negative charge on hydrogen evolution the cells have been placed on a short orbit shallow cycling regime. The gas from each cell was periodically analyzed for hydrogen, (Figure 13). It can be seen that the cells which were initially charged beyond 80% of the Cd began to generate hydrogen and build up pressure at the start of the cycling regime. The cells which were charged to 50 and 60% of theoretical, however, showed no hydrogen evolution after 335 cycles.

The cells were given a capacity discharge after 400 cycles. The data are shown in the table below:

<u>Extent of Theor. Charge</u>	<u>AHc</u>	<u>AH1</u>	<u>Limiting Discharge</u>	<u>Electrode Charge</u>
50%	2.85	2.80	Negative	Positive
60%	3.2	3.2	"	"
80%	3.35	3.4	"	Pos. & Neg.
90%	3.2	3.1	Pos. & Neg.	Negative
100%	3.4	3.5	Pos. & Neg.	Negative

The capacities of the cells charged above 60% are quite good, considering their outputs at cycle 3 were about 3.75 ampere hours.

The capacity of the cell charged to 50% of Cd is also satisfactory. It now becomes evident that cells charged to about 60% of theoretical are preferable for use on a rapid cycling regime, since the excess cadmium oxide provides a better margin of safety against hydrogen evolution without harming the performance.

2.3 Trickle Charging

NASA had reported some data on the initial pressure rise and subsequent decay which occurs in sealed cells during extended trickle charging. In order to study this phenomenon in greater depth, cells from which all excess electrolyte was removed were instrumented with pressure gauges and reference electrodes, and placed on trickle charge at 0.1 mA/in^2 . Gas analyses along with positive and negative reference voltage measurements were taken at regular intervals in an effort to relate the pressure decay with changes in gas composition and individual electrode potential. These data are plotted in Figure 14. The initial pressure rise can be related to a rise in the concentration of hydrogen and negative electrode potential. When the potential of the positive electrode began to increase to its maximum and generate oxygen, the hydrogen concentration began to decrease along with the cell pressure.

Since hydrogen scavenging by the positive electrode is known to occur at a very low rate at open circuit, it is evident that hydrogen recombination is potential dependent and greatly increases positive voltage. Some evidence of hydrogen reaction with oxygen at the nickel sites of impregnated cadmium electrodes have been reported by Seiger & Shair. This mechanism may also be responsible for the observed pressure decay, in pressed plates.

2.4 Review of Studies in Phase 2

The mechanism of gas recombination has been found to be kinetically limited on cadmium. Rotating disc electrode (RDE) studies showed that recombination is much faster on silver and on nickel than cadmium. The reaction on a rotating silver electrode slows down after a short initial period, which is also the case in cells. The effect may be due in part to impurity adsorption on the silver.

The RDE work on cadmium covered the electrolyte range from 45% down to 31%. Lowering the electrolyte concentration from 38 to 31% increases the oxygen recombination rate by a factor of 2.5. However, the rate of oxygen reaction with cadmium is decreased about 2.5 times in the presence of soluble separator debris, and since the degradation products from cellulose greatly increases as the electrolyte concentration is lowered, using 31% KOH is not advantageous. The optimum concentration for oxygen recombination is yet to be determined but must be between 31-38% KOH.

The pressure decay reported by NASA when cells (which have become negative limiting) are trickle-charged has been confirmed. Gas analyses and reference electrode readings indicate that the decrease in the concentration of hydrogen can be correlated to the break in the cell potential curve. This break is caused by the silver electrode reaching a full state of charge. When cells are given shallow discharges between long trickle charges, there is a sudden increase in the oxygen concentration at the beginning of each discharge. The rise is thought to be due to the release of occluded oxygen from the silver electrode.

As has been stated, the effect of electrolyte quantity has been studied in cells with intermediate quantities of KOH between the normal quantity and no free electrolyte. Removing all the free electrolyte from cells with woven nylon interseparators increases oxygen recombination about 50%, but results in a 30% loss in initial cell capacity. However, substitution of highly absorbent Pellon for the nylon allows all free electrolyte to be removed without decreasing cell capacity.

Gas recombination has been increased by using partially wet-proofed cadmium electrodes. The process of wet-proofing does not appreciably decrease electrode efficiency. As in case of normal plates, the recombination rate of the treated plates decreases with cycling, but still remains superior.

3. Phase 3 - Constant Potential Charging

The loss of argentic voltage as a result of prolonged constant potential charging is being investigated in this phase of the program.

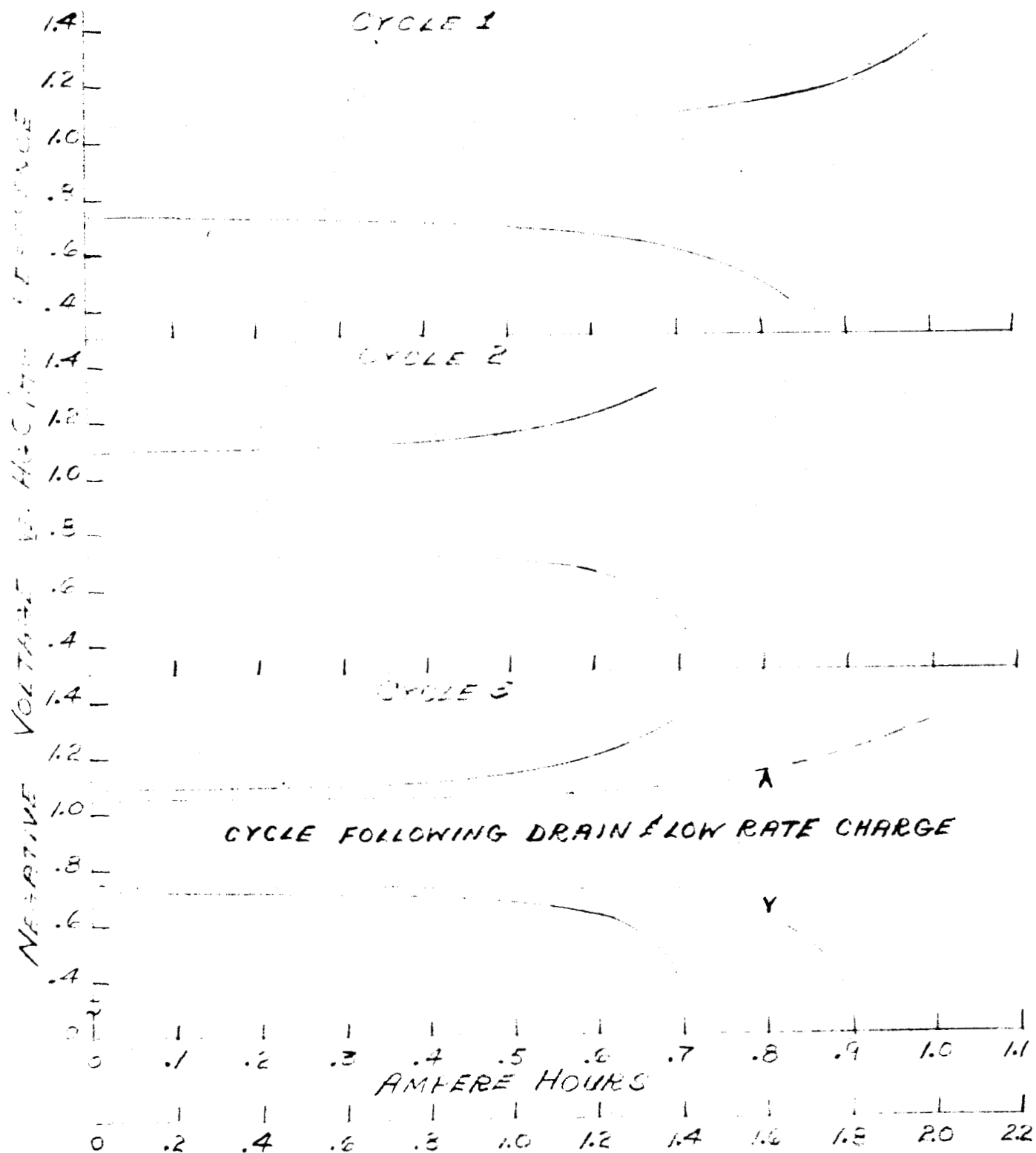
Attempts to analyze the positive plates chemically were not successful, but the technique has since been improved, and further work should be done.

4. Phase 4, Argentous Level Operation

The effects of conductive additives to increase the argentous efficiency have been studied in this phase of the program. Cells were constructed with HC, FR and MR silver powders mold pressed to 4.8 g/cc. The silver powders were initially doped with either palladium or lead before being fabricated into electrodes. After 94 cycles, the cells made with MR and FR silver plus 1% Pd have the best performance and are delivering about 49% of theoretical Ag_2O utilization. The data for all the cells are presented in Figure 15.

CYCLED NEGATIVE ELECTRODE
PERFORMANCE DATA - SHORT ORBIT
(AFTER 1200 CYCLES-HIGH RATE CHARGE)
(PREPARED (X10))

$I_C = 0.5 \text{ mA}/10^3$
 $I_D = 100 \text{ mA}/10^3$



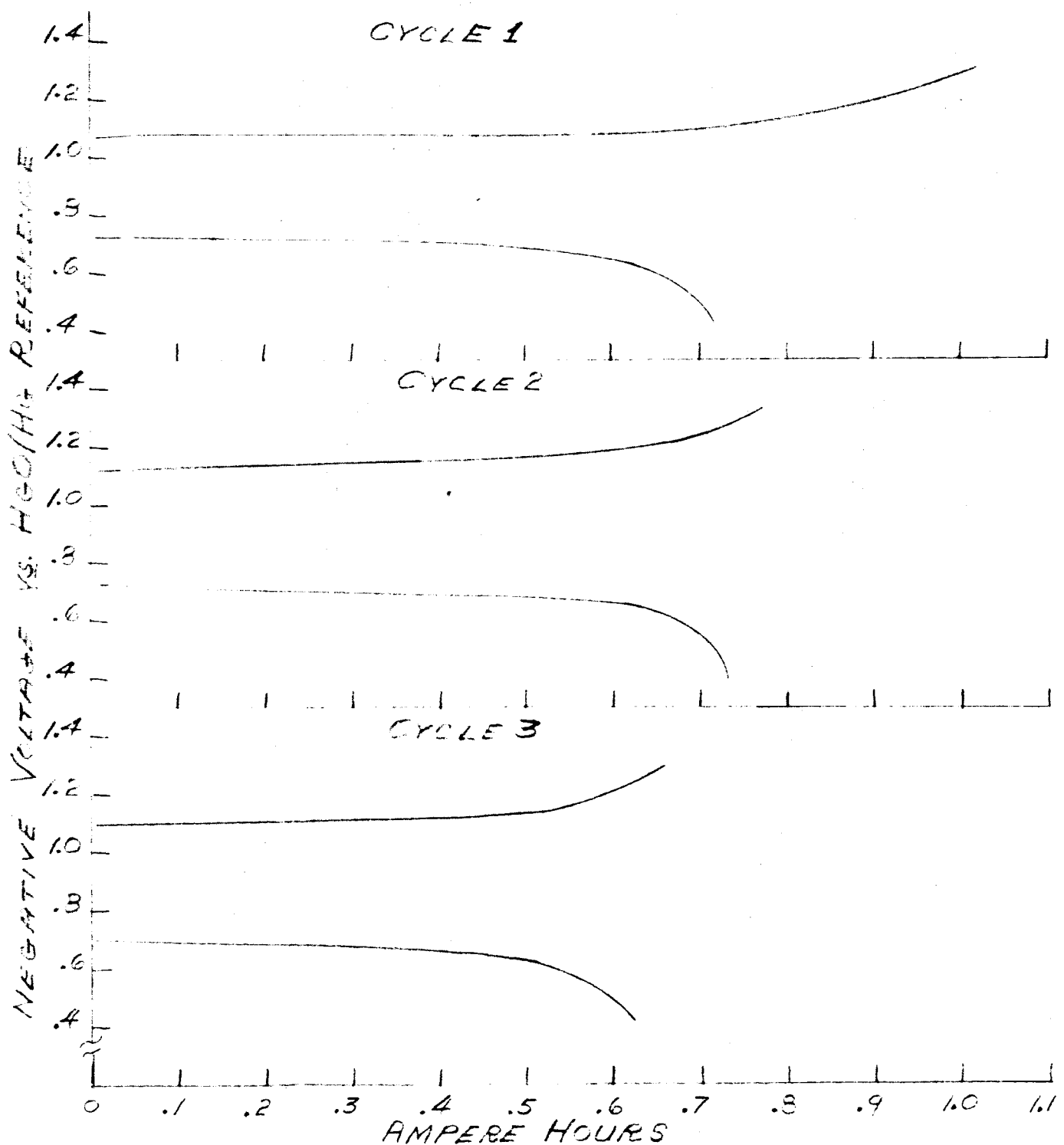
**GRAMS Cd UTILIZED

**TOTAL Cd Wt. = 4.45g

Sig.1

CYCLED NEGATIVE ELECTRODE
PERFORMANCE DATA-SHORT ORBIT
(AFTER 1200 CYCLES-HIGH RATE CHARGE,
(IMPREGIATED Cd)

$I_c = 65 \text{ ma/in}^2$
 $I_D = 100 \text{ ma/in}^2$



**GRAMS Cd UTILIZED

**TOTAL Cd WT. = 3.50g

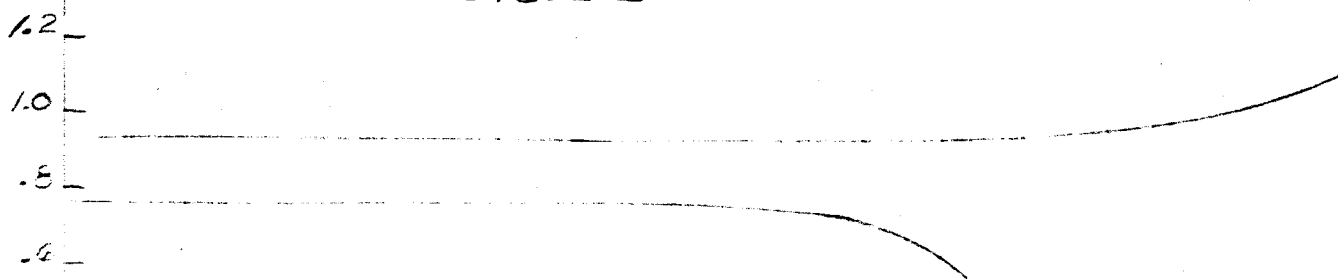
Fig. 2

CYCLED NEGATIVE ELECTRODE
PERFORMANCE DATA - SHORT ORBIT
(AFTER 1200 CYCLES - LOW RATE CHARGE)
(PRESSED CdO)

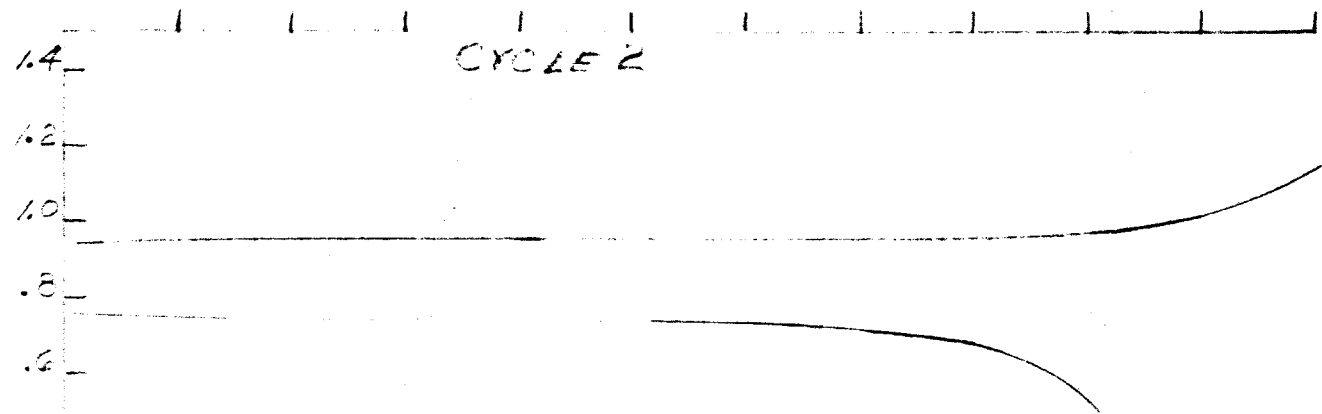
$I_c = 19 \text{ mA/in}^2$
1.4 $I_D = 100 \text{ mA/in}^2$

CYCLE 1

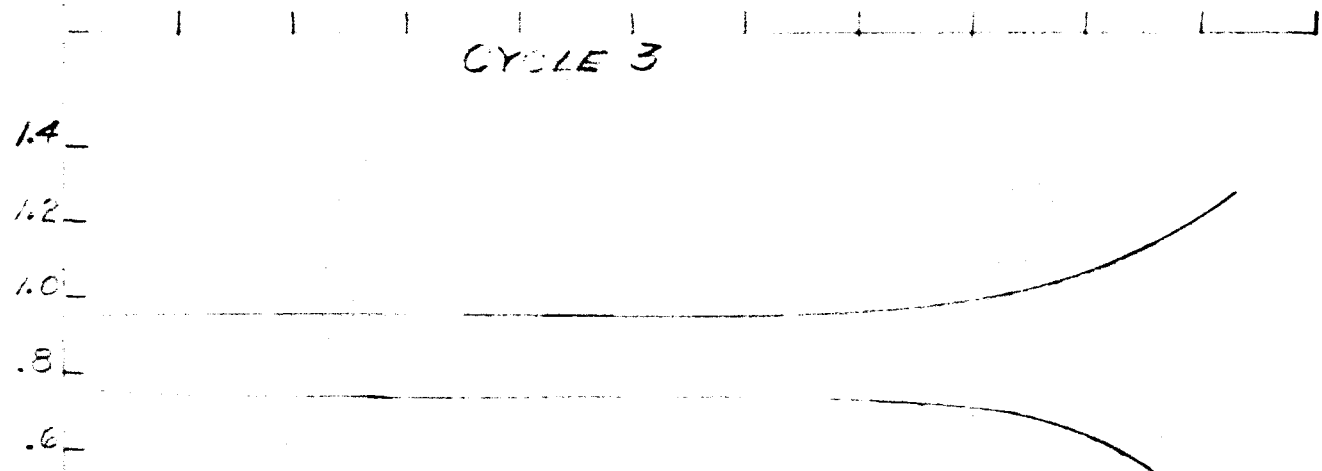
NEGATIVE VOLTAGE VS. HGO/HG REFERENCE



CYCLE 2



CYCLE 3



0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0 1.1
AMPERE HOURS

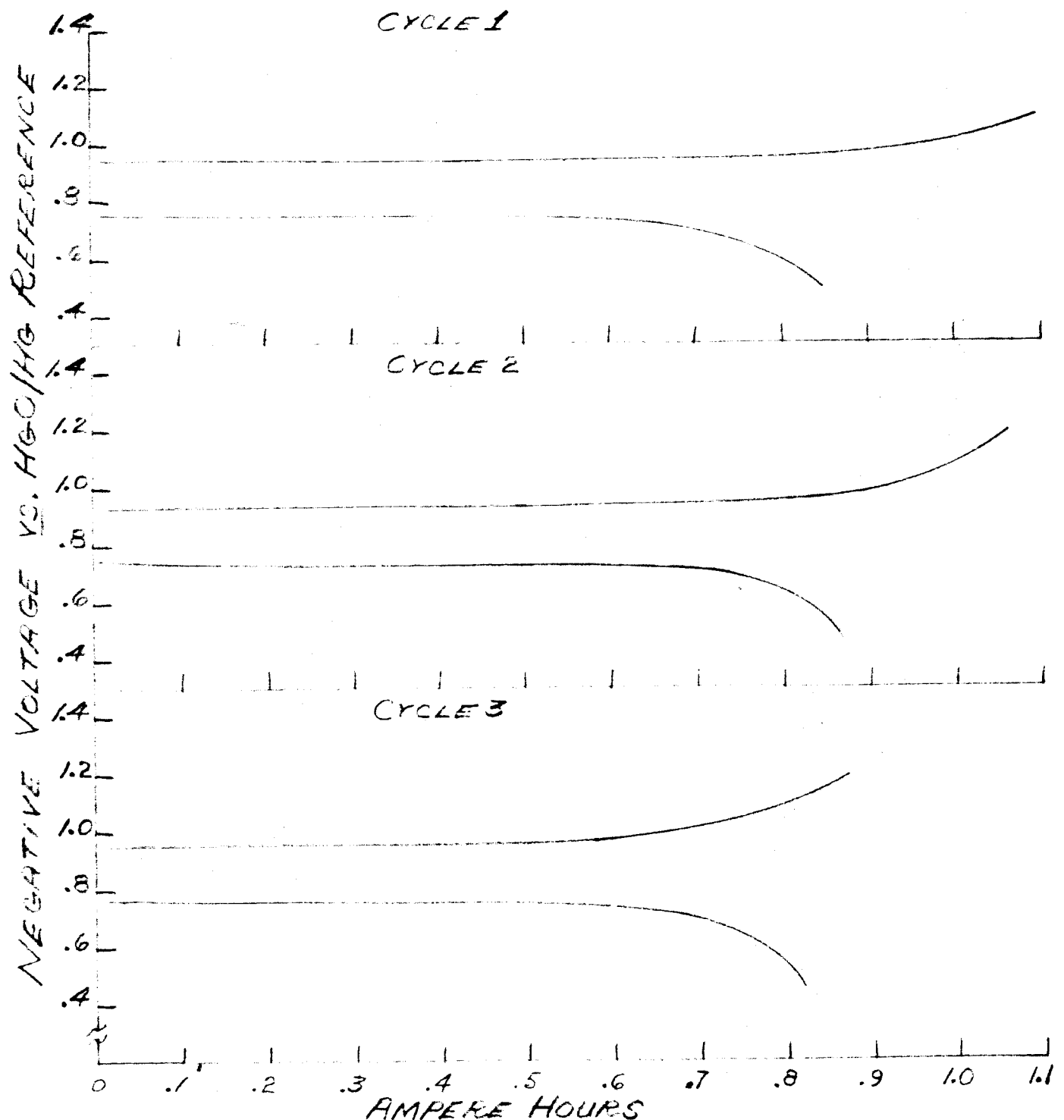
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0 2.2
GRAMS Cd UTILIZED

** TOTAL Cd WT = 4.5 g

Fig. 3

CYCLED NEGATIVE ELECTRODE
PERFORMANCE DATA-SHORT ORBIT
(AFTER 1200 CYCLES-LOW RATE CHARGE)
(IMPREGNATED Cd)

$I_C = 19 \text{ ma/in}^2$
 $I_D = 100 \text{ ma/in}^2$



** GRAMS Cd UTILIZED

** TOTAL Cd WT = 3.4g

Fig. 4

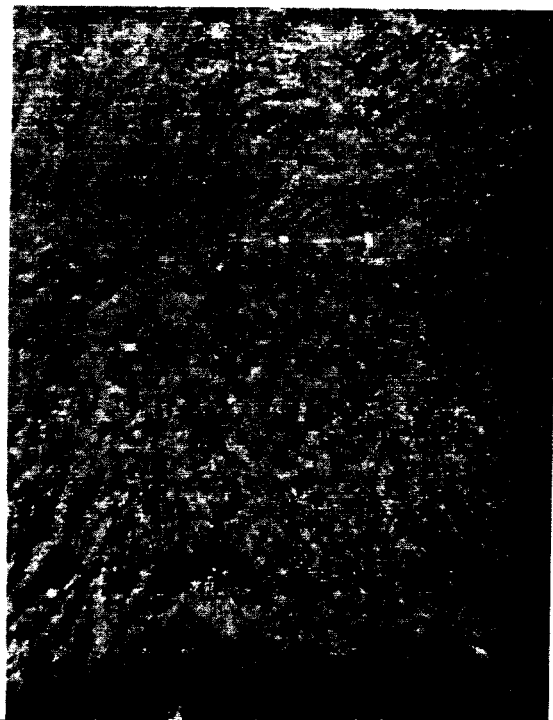
FRESH Cd ELECTRODE
(FULLY CHARGED)



100 X



200 X



400 X

CYCLED Cd ELECTRODE - CELL 6
(1201 CYCLES)



100X

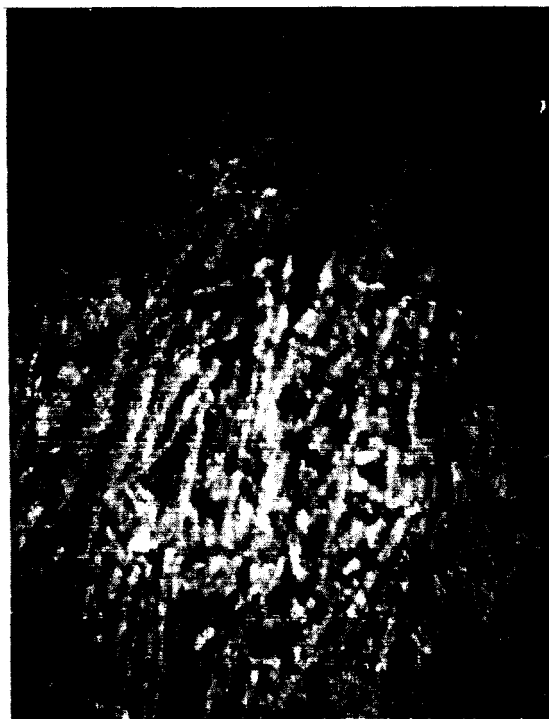


200X-POLARIZED
LIGHT



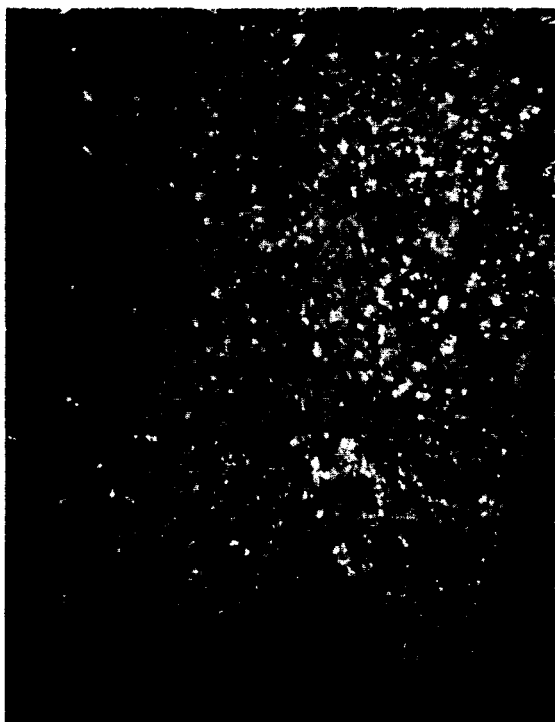
200X-DARK FIELD

CYCLED Cd ELECTRODE-CELL 6
(1201 CYCLES)

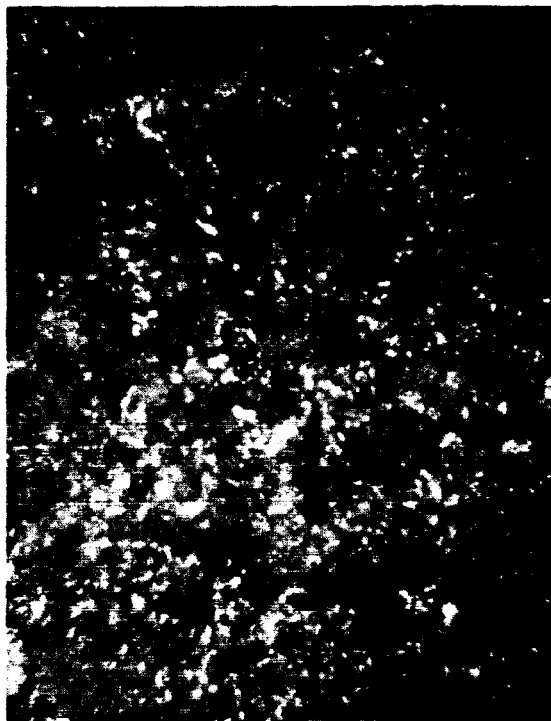


400 X

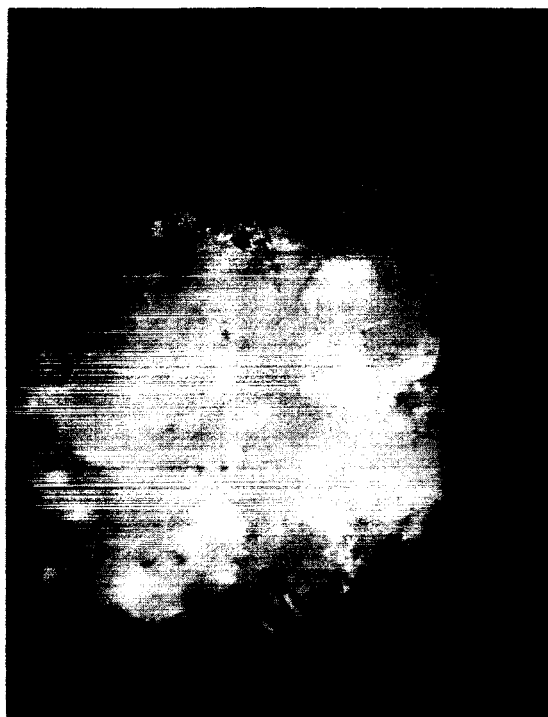
CYCLED Cd ELECTRODE-CELL 70
(1201 CYCLES)



100X - POLARIZED LIGHT



200X - POLARIZED
LIGHT



770X - OIL IMMERSION-
CRYSTAL FACE

TABLE I
CADMIUM ELECTRODE ANALYSES
(AFTER 1201 CYCLES)

CELL NO	ELEC. CONST.	SEPARATOR	%Cd	%Cd(OH) ₂	%CdCO ₃	*AFTER 1201 CYCLES		
						%Cd	%Cd(OH) ₂	%CdCO ₃
6	PRESSED CdO 2.8g Cd/cc	W2NY/6C19	83.5	1.5	15.0	89.7	3.2	7.1
16	PRESSED CdO 2.3g Cd/cc	W2NY/6C19	84.6	2.6	12.8	91.1	2.7	6.2
30	IMPREGNATED Cd	W2NY/6C19	43.1	4.8	8.6	46.7	4.2	5.1
70	PRESSED CdO 2.8g Cd/cc	W2NY/3PVA	81.9	0.4	17.7	84.6	1.5	13.9

ACTIVE MAT. WT = 4.45g
IMP. " " = 6.1g (TOTAL) - 3.4g Cd METAL

* FOLLOWING A CHARGE AT 19ma/in²

EFFECT OF NEGATIVE PLATE DENSITY ON CELL PERFORMANCE (SHORT ORBIT)

$I_c = 65 \text{ ma/in}^2$
 $I_D = 100 \text{ ma/in}^2$

x - 2.3g Cd/cc
○ - 2.8g Cd/cc
● - 3.3g Cd/cc

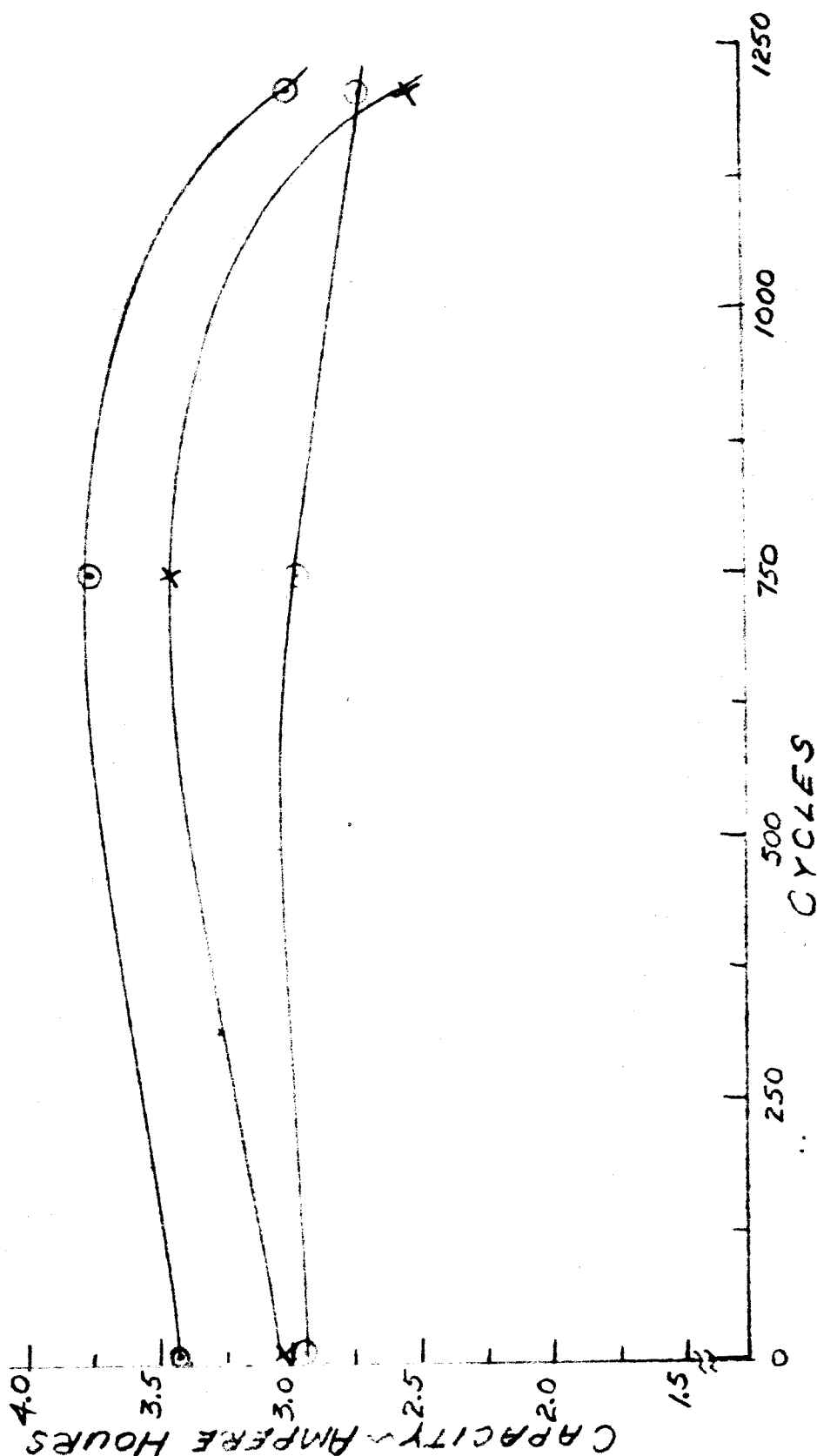
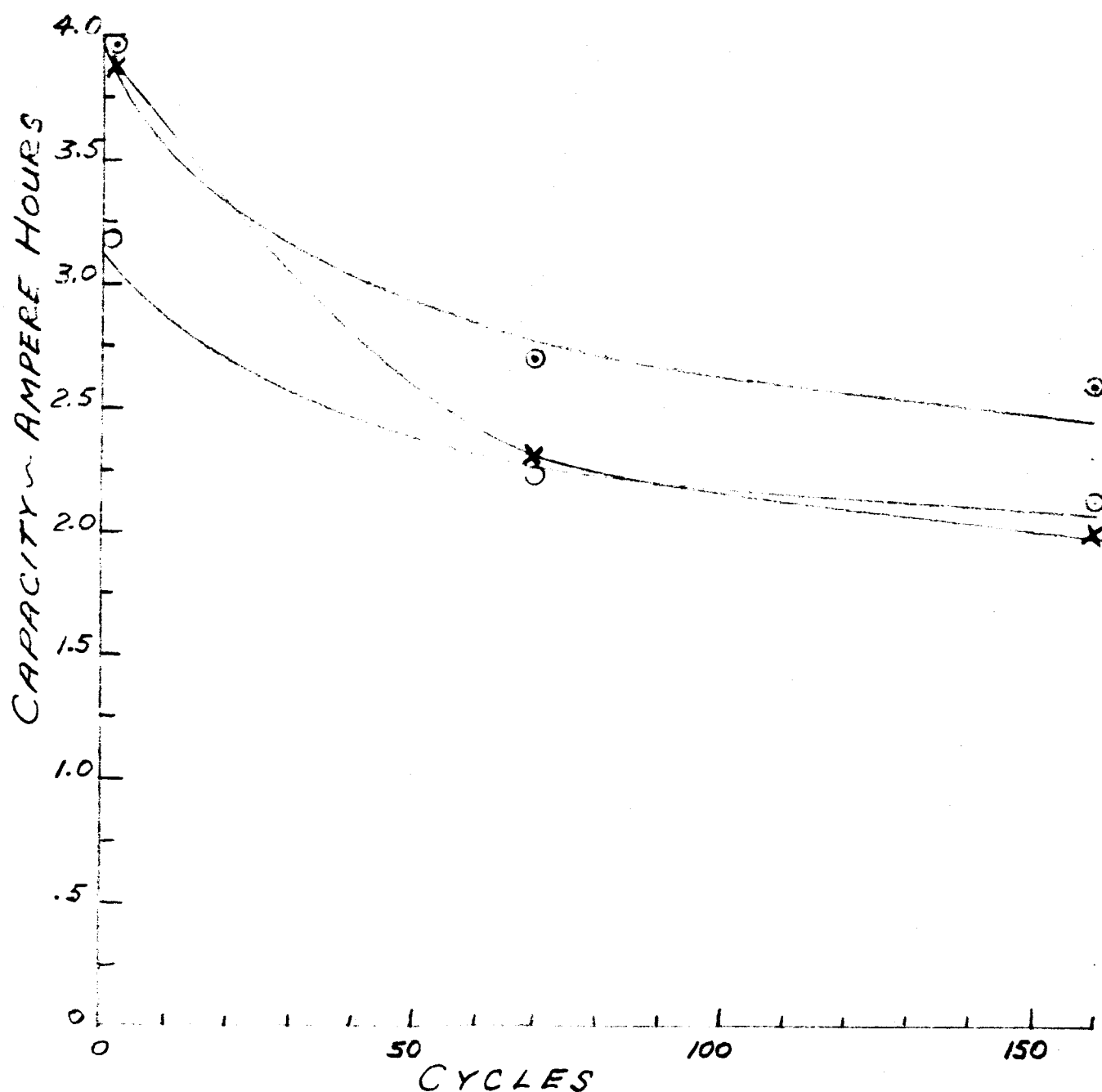


Fig. 6

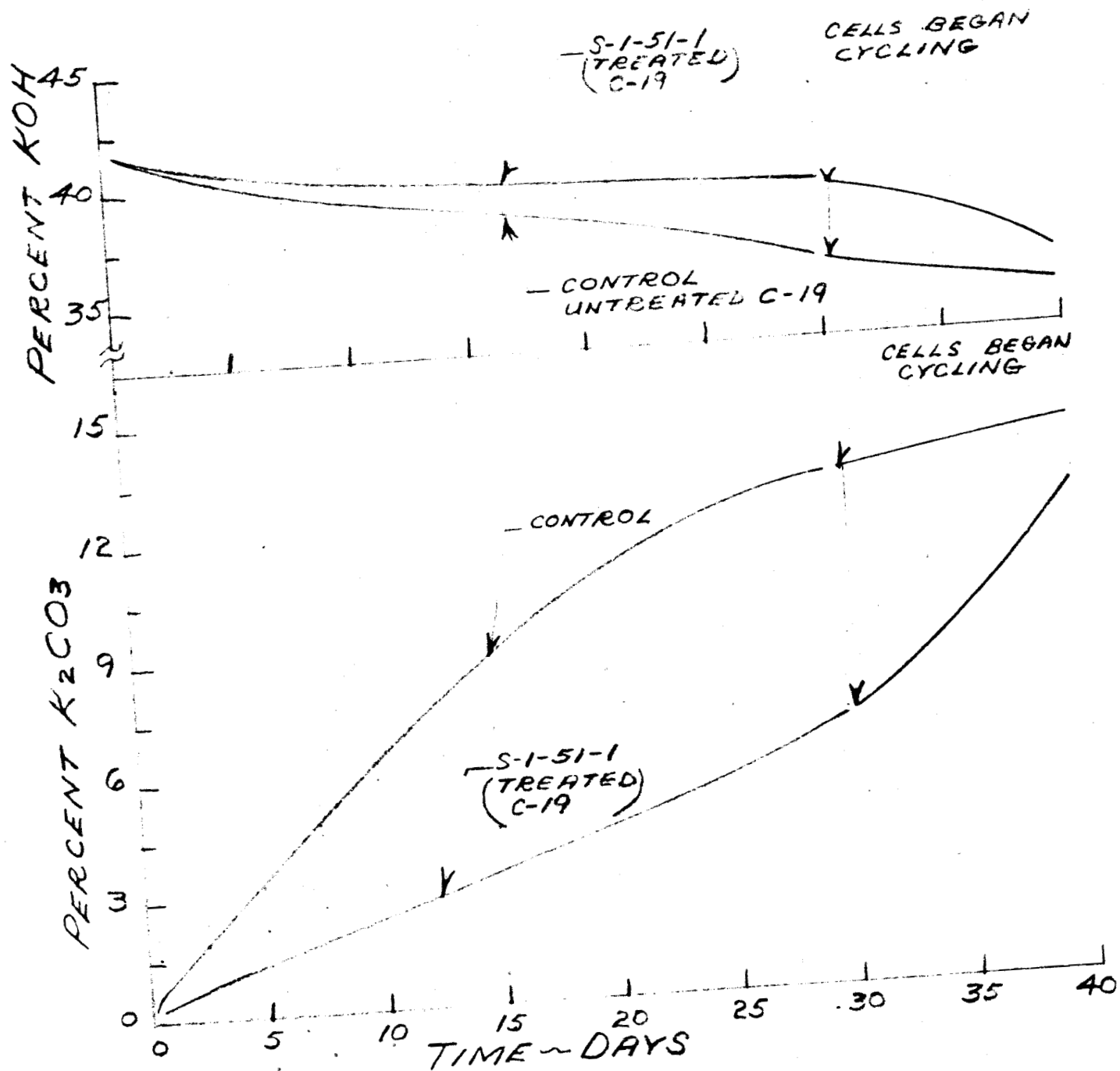
EFFECT OF NEGATIVE PLATE DENSITY ON CELL PERFORMANCE (LONG ORBIT)

$I_c = 5 \text{ ma/in}^2$
 $I_D = 120 \text{ ma/in}^2$

x-2.3 g Cd/cc
o-2.8 g Cd/cc
⊙-3.3 g Cd/cc

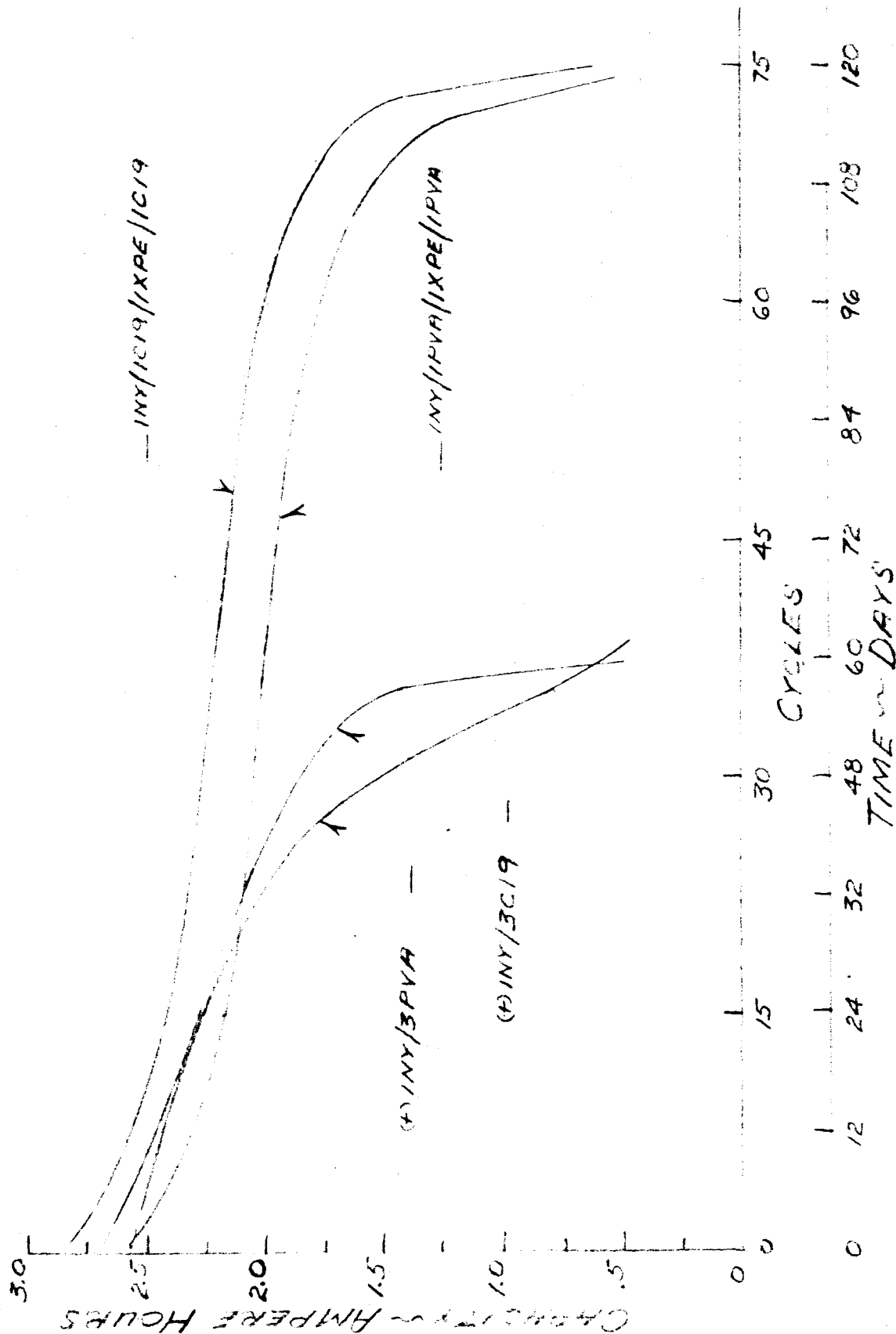


SEPARATOR DEGRADATION TEST - 50°C CELLS INITIALLY FILLED WITH 42% KOH



Sig. 11

PERFORMANCE DATA - 50°C
SILVER SHORTING TEST
CHG @ 65 mA./in.²
DISCHG @ 100 mA./in.²



EFFECT OF EXTENT OF NEGATIVE FORMATION ON HYDROGEN EVOLUTION (100 MINUTE ORBIT-35% D.D.)

SEALED Ag Cd
CELLS

EXTENT OF THEORETICAL CHARGE
ON INITIAL CYCLE

- X — 50%
- △ — 60%
- — 80%
- ⊗ — 90%
- — 100%

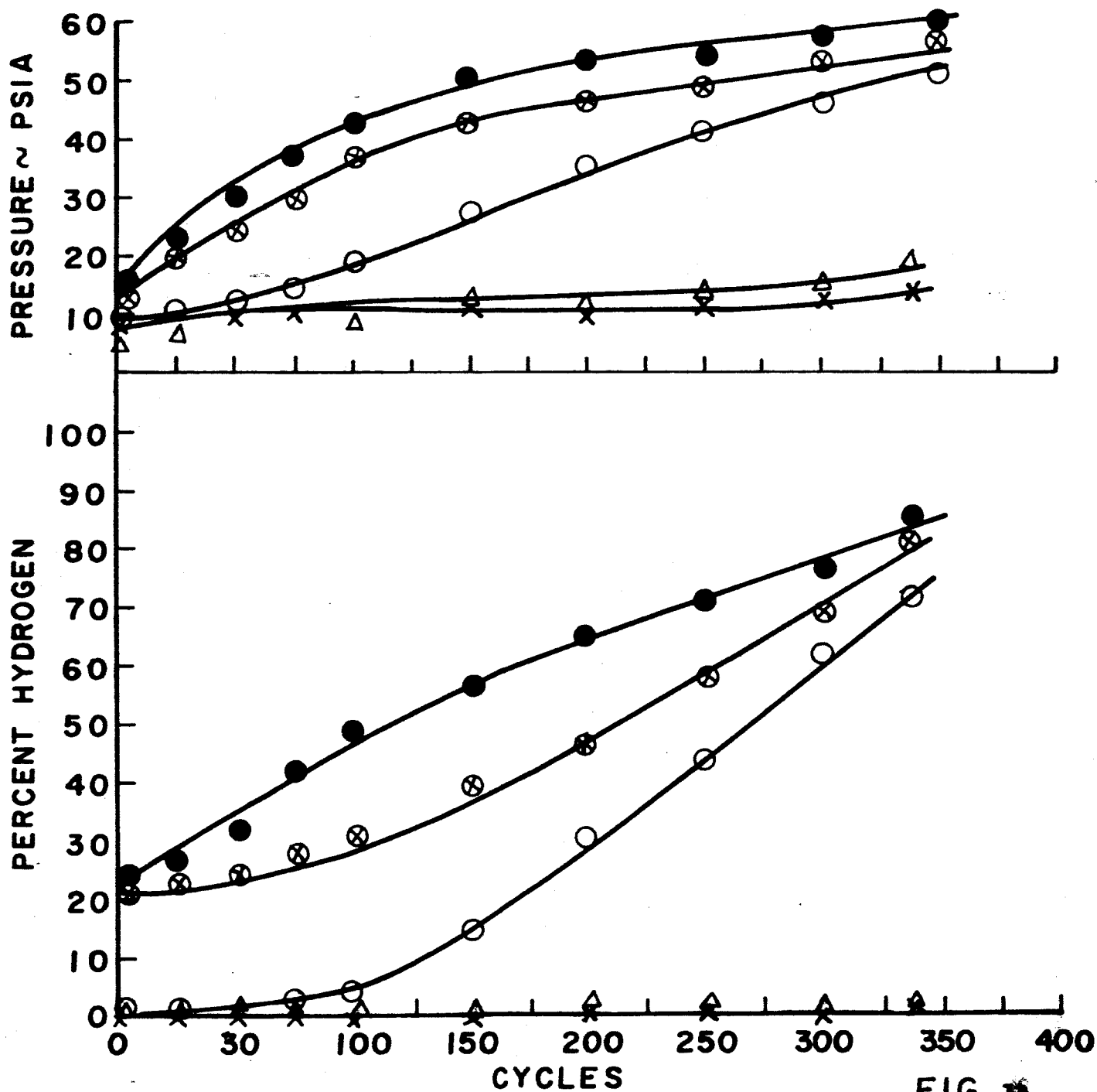


FIG. 15

PROLONGED TRICKLE CHARGING

0.1 MA/IN²

SEALED Ag Cd CELLS
NO FREE ELECTROLYTE

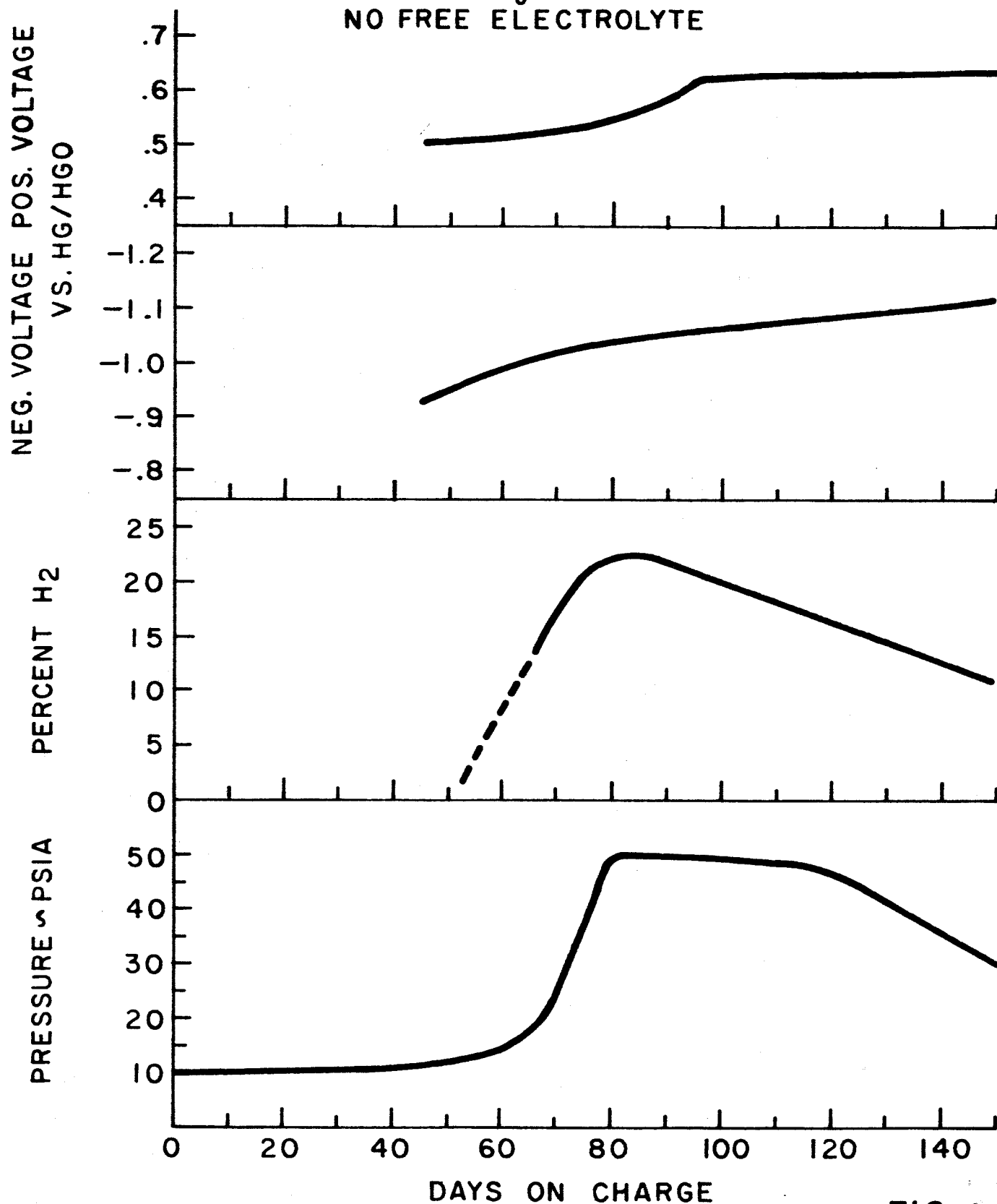


FIG. 14

SINGLE LEVEL VOLTAGE.
 PERFORMANCE DATA - LONG ORBIT
 $I_C = 80 \text{ mA}$ TO 1.35 VOLTS
 $I_D = 2 \text{ A}$ TO 0.6 VOLTS
 CELLS FILLED WITH $4N \text{ KOH}$

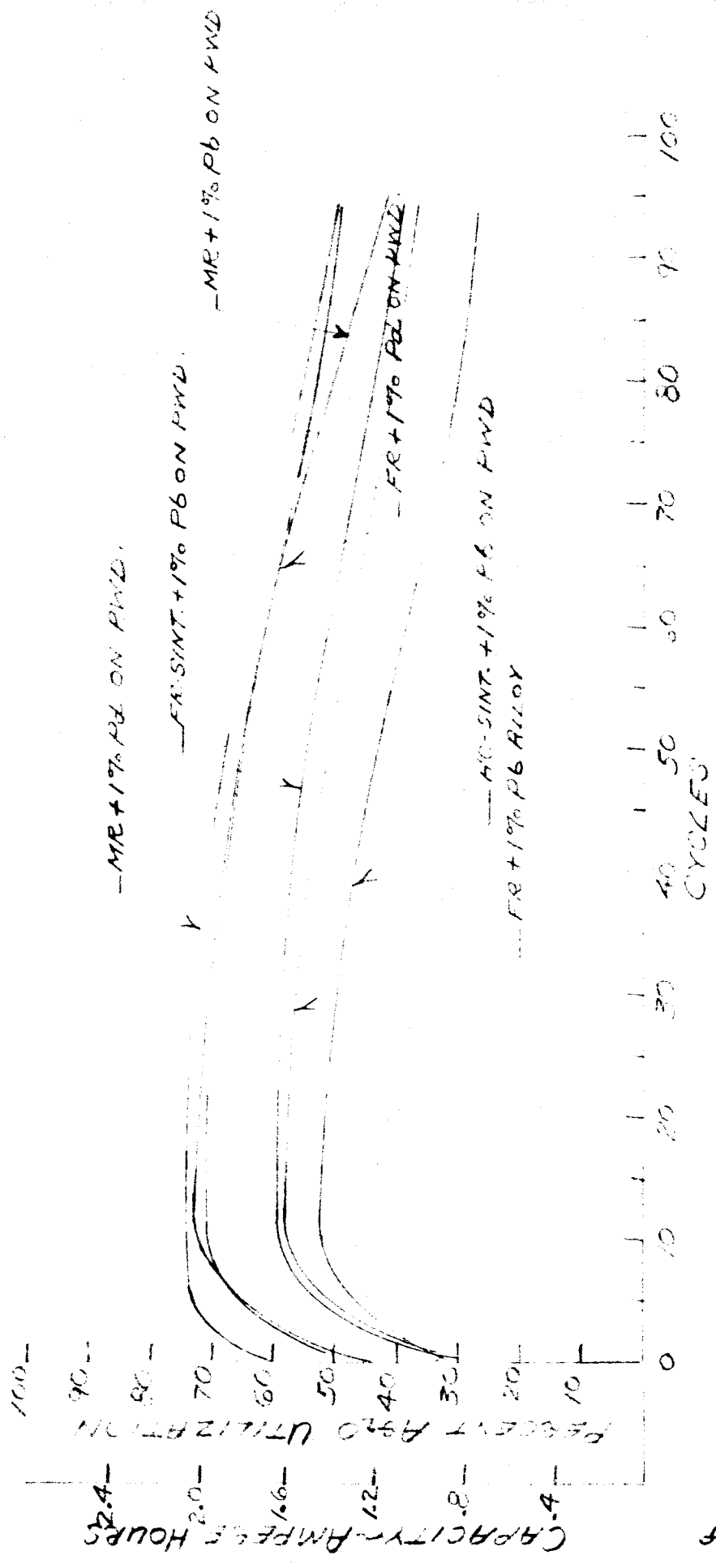


TABLE II
PERFORMANCE DATA - SHORT ORBIT
 (DEEP DISCHARGE AFTER 1200 CYCLES)

CELL No.	AH0	AH1	LIMITING DISCHG.	ELECTRODE CHG.	CELL CONSTRUCTION
2	2.35	2.18	NEGATIVE	NEGATIVE	(+) 4.8g Ag/KC HANSPWD (-) 2.8g Cd/KC
⑥	2.70	2.55	"	POSITIVE	(+) 2NY/6C19 31% KOH " " " " " "
8	3.05	3.0	NEGATIVE	POSITIVE	(+) 4.2g Ag/KC " " " " " " 42% KOH
10	2.91	3.05	"	"	(+) 3.6g Ag/KC " " " " " " " "
* 12	2.25	2.30	NEGATIVE	NEGATIVE	(+) 4.8g Ag/KC HANSPWD " " " " " " "
14	2.57	1.87	"	POSITIVE	" " " " FR PWD " " " " " "
① 16	2.50	2.65	"	NEGATIVE	" " " " (-) 2.3g Cd/KC - PRESSED CdO
18	2.90	2.70	NEGATIVE	NEGATIVE	" " " " (-) 3.3g Cd/KC " " " "
* 22	2.75	2.25	"	"	" " " " PASTED CdO 2.8g Cd/KC
* ③ 30	1.72	1.80	"	"	" " " " IMPREG Cd - 2.8g/KC
36	2.83	2.65	NEGATIVE	POSITIVE	" " " " PRESSED CdO + 5% FR Ag
38	2.45	2.40	"	"	" " " " 2.8g/KC REVERSE WRAP
* 68	2.55	2.15	"	NEGATIVE	" " " " (+) 2PVA/3C19 " " " "
* ⑦ 70	2.35	2.30	"	"	" " " " (+) 2NY/3PVA " " " "

* CELLS HAVE NO FREE ELECTROLYTE IC = 65 mA/in²
 ⑦ CELLS WERE DISSECTED AFTER 1201 CYCLES ID = 100 mA/in²

TABLE III
PERFORMANCE DATA - LONG ORBIT
(DEEP DISCHARGE AFTER 160 CYCLES)

CELL NO	AH0	AH1	LIMITING DISCHG. CHG	ELECTRODE	CELL CONSTRUCTION
1	1.75	1.90	NEGATIVE	NEGATIVE	(+) 4.8g Ag/KC HCPWD (+) 2NY/6C19 31% KOH
3	2.0	2.05	"	"	" " " " " " 36.5% KOH
5	2.15	2.26	"	POSITIVE	" " " " " " 42% KOH
7	2.46	2.25	"	"	(+) 4.2g Ag/KC " " " " " " "
9	2.10	1.90	"	NEGATIVE	" 3.6 " " " " " " "
11	2.0	1.6	"	"	(+) 4.8g " " HAHSPWD " " " " " "
13	1.83	1.85	"	"	" " " " FR " " " " " "
15	2.0	1.75	"	"	" " " " PRESSED CdO 2.3g Cd/KC " " " "
*17	2.60	-	NEGATIVE	-	" " " " 33 " " " " " "
*21	2.45	-	POSITIVE	-	" " " " PASTED CdO 2.8 " " " " " "
*27	2.50	-	POSITIVE	-	" " " " " " " " " " " "
*29	1.51	-	NEGATIVE	-	" " " " IMPREG. Cd " " " " " "
31	2.26	2.15	"	"	" " " " PRESS. CdO + 2% SHAW. BLK. " " " "
33	2.56	2.35	"	"	" " " " " " " " GRAPHITE " " " "
35	2.22	2.36	"	"	" " " " " " " " + 5% FR Ag " " " "
37	2.2	2.0	"	"	" " " " " " " " 2.8g Cd/KC REVERSE WRAP
*67	BLEN-UP-CYCLE 110				(+) 3.6g Ag/KC (+) 2PVA/3C19 42% KOH
69	2.32	2.45	NEGATIVE	POSITIVE	(+) 4.8g/KC " " " " " "
71	2.16	2.26	"	NEGATIVE	" " " " (+) 2NY/3PVA " " " "
73	2.10	2.35	"	"	" " " " " " 31% KOH

IC = 5 ma/in²

ID = 120 m.o./in²

* CELLS SHORTED DURING CHARGE

** EQUIPMENT FAILURE

TABLE IV
ELECTROLYTE ANALYSES

SHORT ORBIT CELLS (CYCLE 1200)				LONG ORBIT CELLS (CYCLE 160)			
CELL NO.	% FREE KOH	MG/ML K ₂ CO ₃	CELL NO.	% FREE KOH	MG/ML K ₂ CO ₃	CELL NO.	% FREE KOH
2	25.8	225	1	21.5	280		
6	31.6	158	3	23.8	230		
8	34.5	141	5	25.0	235		
10	35.1	130	7	24.5	250		
14	32.3	145	9	25.8	229		
16	33.3	137	11	28.3	215		
18	31.6	138	13	22.1	265		
36	34.1	135	15	23.5	238		
38	31.1	162	31	25.5	240		
			33	27.7	220		
			37	24.1	255		
			69	20.5	291		
			71	19.8	299		
			73	15.4	315		

TABLE V

SEPARATOR DEGRADATION TEST - 50°C CELL PERFORMANCE DATA

SEPARATOR SYSTEM	CYCLE 1		AFTER 30 DAYS @ 50°C		* AFTER 155 CYCLES @ 50°C	
	AH0	AH1	AH0	AH1	AH0	AH1
(+) 2NY/6C-19/(-)	5.0	5.15	3.3	3.4	2.85	2.95
(+) 2NY/6C-19S-1-51-1/(-)	5.37	5.5	3.4	3.35	2.90	2.95
(+) 2NY/3 VISKING/(-) (FIBROUS)	5.4	5.4	3.85	3.95	3.17	3.15
(+) 2NY/3 VISKING S-1-51-1/(-) (FIBROUS)	5.6	5.75	4.05	4.0	3.33	3.35

* 155 CYCLES REPRESENTS 50 DAYS TOTAL TIME AT 50°C

$I_c = 6.5 \text{ m}^2/\text{in}^2$

$I_D = 100 \text{ m}^2/\text{in}^2$

TABLE VI
PERFORMANCE & RECOMBINATION DATA
WET PROOFED CADMIUM
(AFTER 1200 CYCLES)

CELL CONSTRUCTION	CAPACITY AHO	AHC	LIMITING DISCHG.	ELECTRODE CHARGE	* RECOMBINATION RATE mA/in ² @ 45 PSIA
(+) 2 NY/6 C19 FREE ELECTROLYTE	2.85	2.70	NEGATIVE	POSITIVE	0.8 mA/in ²
2 NY/6 C19 NO FREE ELECTROLYTE	2.10	2.0	"	NEGATIVE	1.3 " "
1 PELLON/4 C19/1 PELLON FREE ELECTROLYTE	2.67	2.60	"	POSITIVE	2.1 " "
1 PELLON/4 C19/1 PELLON NO FREE ELECTROLYTE	2.65	2.60	"	POSITIVE	2.9 " "

CHARGE RATE = .91A
DISCHG " = 1.7A

* INITIAL O₂ RECOMBINATION RATE = 15-20 mA/in² @ 45 PSIA

NOTE:

STANDARD Cd ELECTRODE GAVE 0.3 mA/in² @ 45 PSIA @ 1200 CYCLES